

## **The Ecology and Acoustic Behavior of Wintering Minke Whales in the Hawaiian and Pacific Islands**

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### **LONG TERM GOALS**

This effort supports a long-term goal for better knowledge of marine mammal species densities at the U.S. Navy's (USN) Pacific Missile Range Facility (PMRF) instrumented range located off Kauai, Hawaii. Establishing long and short term marine mammal species density baselines at USN instrumented range facilities will allow better understanding of changes observed from activities such as mid frequency active sonar training exercises. Species density trends over multiple years can be invaluable in understanding the health of local populations.

### **OBJECTIVES**

This effort is focused on Central North Pacific minke whales (*Balaenoptera acutorostrata*), of which little is known when they are in Hawaiian waters due to very limited visual sightings. The objective is to use USN range hydrophones' passive acoustic data to detect, localize, and estimate densities of minke whales in the area from their boing vocalization. Obtaining a long term average minke boing cue rate is a major objective of the effort being done in collaboration with Biowaves and the Univ of St Andrews. The boing cue rate will enable estimating vocalizing minke whale density from the range sensors minke boing density estimates. A secondary objective is to perform near real-time localization of minke whales using the USN hydrophones in order to radio to a field team to improve encounter rates and potential understanding of animal behavioral states (directed search).

### **APPROACH**

This effort is in partnership with concurrent efforts by Tom Norris (Biowaves), Vincent Janik and Len Thomas (Univ of St. Andrews) and Eva Nosal (Univ of Hawaii). Biowaves leads a field effort involving a surface craft towing hydrophones to conduct an acoustic line transect survey for obtaining vocalizing minke whale abundance. Directed search efforts also allow getting close to minke whales for studying their behavior. Density estimation using the Navy hydrophones is currently conducted for boing density; however by analyzing data concurrent with the field teams' survey effort, and given

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the calling whale abundance from the survey result, a long term boing rate can be derived in order to estimate the calling minke whale density from the Navy hydrophones. The Univ of St. Andrews effort supports analysis of survey platform towed acoustics, survey design and density estimation methodology. Eva-Marie Nosal at the Univ of Hawaii collaborates in the area of localization validation and accuracy.

## **WORK COMPLETED**

The 2010 field season began late February and ended 12 April 2010. Effort in February was directed at utilizing a faster platform (R/V Tropic Bird), integrating acoustic towed, and sonobuoy, sensors and conducting directed search on the PMRF Barking Sands Underwater Range Expansion (BSURE) instrumented range area. This range has 15 operational hydrophones used in this study and is located well offshore which requires significant transit time when departing from the Port Allen / Waimea area of Kauai. Only two days of directed search on the range were performed (24 and 27 Feb 2010) with limited success primarily due to limited effort. A minke whale was being pursued on the second day of directed search; however final closure and visual sighting did not occur. This is in comparison to the 2009 field season in which several days of directed search effort were expended with one visual sighting resulting from pursuit of 3 different animals on three different days.

The remainder of the 2010 field season (1 March through 11 April) involved using the quiet motor sail boat R/V Dariabar to conduct the acoustic line-transect survey. This vessel's quiet nature helps minimize potential animal reactions to the survey vessel, and she is large enough for spending multiple days at sea. Total survey effort was approximately 132 hours in twelve days on the range. Due to security concerns during range operation, concurrent PMRF hydrophone data was collected for 99 hours of the LT effort time. A systematic random sample of the PMRF hydrophone data was performed for use in acoustic density estimation. Eleven hours of sample data was obtained by concatenating the available acoustic data and taking ten minute samples every 90 minutes from a random start time.

Acoustic boing density estimation using PMRF hydrophones was conducted using spatially explicit capture recapture (SECR) methods (Borchers and Efford, 2008) similar to a pilot effort using 2006 and 2007 data (Marques et.al, 2010). This effort differs in that a spatial habitat mask is utilized and density estimation is completely obtained using SECR methods vice using SECR to obtain the detection function and utilizing cue count methods to obtain density. Figure 1 provides an illustration of the SECR study area (dotted areas) showing the approximate location of the hydrophones (crosses), the island areas (gray) with estimated acoustic shadow zones (no dots) involved and the approximate surface acoustic line transect survey area (boxed around the sensors). The analysis is implemented in R (R Development Core Team, 2009) using the secr() package (Efford 2009). By utilizing a large amount of sample data (over 10% of the total data available as compared to under 1.3% in Marques et.al. 2010) the density analysis is performed completely in secr() and does not include the use of cue counting on a larger data set. The overall area shown in figure 1 is relatively large to ensure that the probability of detecting a cue from a sensor is less than 0.01, in this case of using a half normal detection function model a buffer distance of 120km is used.

The approach of using secr() to fully determine the density requires 100% manual validation of boing associations for all eleven hours of sample data. Improvements were made to three processes (boing

detection, boing association and manual validation) previously employed in the DECAF effort (<http://www.creem.st-and.ac.uk/decaf/>). The automated boing detection (based on Mellinger et.al., 2010; Morrissey et.al., 2009) improvements include improving spectral resolution (0.73 Hz vice 5.8 Hz) and obtaining the detections precise frequency and maximum energy level and the ratio of the detection energy to the average energy over the detection band (1350-1440Hz). The improved resolution frequency feature enables better association, as frequency is an important feature in the association process. In addition, the frequency feature has been observed to be very stable as reported in last years report (one individuals frequency over nearly 6 hours = 1384.4 Hz, n=55, stdev=1.55Hz) and is a feature which helps identify individuals. Depth of the sensor is utilized as a covariate in `secr()`.

Use of `secr()` to perform density estimation requires that no single sensor can report one event more than once. This requires that multipath, segmentation, and false positive reports must be removed from the data which was implemented in the automatic association process (assigning a single boing call to detections received on multiple hydrophones with large spatial separation). The association process was also improved by adding a hydrophone to hydrophone maximum time delay matrix, which improved upon the previous method which used two fixed temporal windows. The improved frequency resolution from the detector also improves the boing association process (a single boing will be received at very close to the same frequency on all hydrophones). The manual validation process was improved by adding features such as: clicking on detections to call up their spectra: and streamlined spectrogram and audio review of individual detections.

An automatic localization process was also developed in light of the improvements to the detection and association processes. The automatic localization also takes advantage of the fact that a single boing calling minke whale tends to output boings repeatedly over multiple hours duration. Automatic localizations are performed using four hydrophones with a signal strength threshold. Temporal integration of localizations reinforces actual whale locations while integrating out erroneous localizations which tend to not repeat spatially. Incorrect localizations can occur for various reasons such as false detections, incorrect associations, and erroneous start times. This automatic localization process will be utilized in helping validate LT encounters, and may provide abundance estimates with limited manual validation/analysis effort. Figure 2 provides a sample screen shot of a 'movie' of automatic localizations for 10 April 2010 at 10:16 HST showing the Dariabar (red diamond), range hydrophone approx locations (circles the green identify those used in the last localization), minke whale probable locations (dark circles). These automatic localizations are easily run in matlab for disks full of raw acoustic data. Investigation of data from 06 April 2010 at 21:00 revealed rapid boing rates for an individual as previously reported (Thompson and Friedl 1980) which are important to understand in terms of how often they occur so the sampling properly captures the bimodal nature of the boing rate. This high boing rate is not often observed in the data, and only occurred for a relatively short period of time (3 hr for this case). As this was at night and not during the LT analysis, it was not captured in the current analysis.

## RESULTS

The primary objective in 2010 of obtaining a long term boing cue rate from the Tom Norris lead acoustic line transect (LT) survey has been accomplished. Preliminary calling minke whale average abundance, as determined using distance sampling methodology conducted by collaborators Norris

(Biowaves award), Thomas and Janik (Univ St. Andrews award), is in the range of 0.00445 to 0.00591 whales over the survey area depending upon which detection model is utilized (animals response to survey craft by going quiet or moving away). The survey area is 1,900 km<sup>2</sup> centered over the USN range hydrophones. This equates to a preliminary average abundance of 8.45 to 11.23 minke whales for the LT survey. The minke being density estimated using the USN hydrophones during the survey time is 71.65 boings per 10,000 km<sup>2</sup> (se=4.1, 95% confidence intervals 63.8 to 80.4). Combining these results allows estimating the long term minke being cue rate as being between 1.21 and 1.61 boings per hr per individual. These results are preliminary as the LT analysis still has to complete encounter validations.

A secondary objective of utilizing USN hydrophones to direct a field team to locations of vocalizing minke whales was also completed with one successful visual sighting (rare for Hawaii) in the 2009 field season. No visual sightings occurred in 2010 due to limited directed search effort and the priority being on conducting the LT survey. In the two days of directed search effort this year, the surface craft was directed to within a few km of one animal, although no visual sighting resulted. Localization accuracy for minke whales utilizing the USN hydrophones was confirmed as being good quality (errors < a few hundred meters for animals on the range) by collaborator Eva Marie Nosal under her Univ of Hawaii award (N0001410352).

For the 11 hours of sample data there were 4,713 automatic detections, of which 3,754 (79.6%) were manually validated as being detections and associated into 1,100 unique associated boings. This SECR analysis builds upon the pilot study (Marques et.al. 2010) with incorporation of a habitat mask (areas animals are not possible, or it is not possible to detect them if present) and use of the water depth as a covariate in the analysis. The half normal detection function model, with the habitat mask shown in figure 1 and with the detection function parameter different for each sensor depth performed best on the data in analysis to date, as determined by the Information Criterion (AIC) when compared to other detection function models. The habitat mask included the island masses, and the estimated acoustic shadow zones due to the islands. The different detection functions (one for each hydrophone depth) with shallower hydrophones having shorter detection distances for the same probability of detection are shown in figure 3.

The previously mentioned being density determined over the 11 hours of sample data is 71.6 boings per 10,000km<sup>2</sup> per hr (SE=4.2, 95% confidence intervals 63.8 to 80.4). This estimate is in the area of the estimate from Marques et.al. 2010 using one hour of sample data from 2006 and 2007 (est. being density =47.88 with SE=10.6, CI: 40.2 to 72.1) and exhibits less error with lower confidence intervals. A DECAF case study of 167 hours of data from Feb-Apr 2006, which used two hours of sample data, half normal detection function with habitat mask and cue count methods (Martin et.al. in prep) shows higher values of being densities (est. density = 120.1, CI: 99.14-145.6) than this study. The times analyzed are different, so actual densities could be different as the results indicate. The density estimate obtained herein is a more direct approach than using both secr() and cue counting, and the confidence intervals much more readily estimated, at the cost of having to manually validate more data. Manually validating more data also gives one more confidence in the validity of the estimated detection functions fit to the data.

Additional work is continuing in SECR investigating several factors; detection functions with  $g(0)<1$ ; effects of 3D, vs. 2D in the analysis; and signal strength as an observation to improve the detection

function model fit. The preliminary estimated long term average boing cue rate per individual reported here (between 1.2 and 1.6 boings/hr/individual) is a factor of four lower than the previously estimated long term boing rate for the one individual sighted in 2009 over a single 10 hour period (5.4 boings per hr/individual). The LT encounters shown herein are preliminary and still require final quality assurance which may alter the calling minke whale abundance results from the LT distance sampling analysis. Additional analysis of existing bottom hydrophone data will help confirm LT encounters.

It is always helpful to list some pertinent assumptions explicit in this analysis such as: 1) Assumption that  $g(0)=1.0$  which is currently under investigation using existing data in the secr() framework; 2) the Poisson distribution of animals may be violated if the minke do prefer to utilize off shore areas (methods in secr also can handle this); 3) boing vocalizing minke whales would tend to emit boings with source levels of on the order of 150dB re uPa (if the call is a mating display, they would be emitted at low levels); 4) sufficient sample periods are obtained to properly represent periods of high boing rates.

## **IMPACT / APPLICATIONS**

These results are a significant step in the ability to provide a first marine mammal species density baseline for an USN instrumented range facility. The Mar-Apr 2010 calling minke whale density estimate is available and tools have been developed, and improved, for continuing the minke whale baseline. The use of USN range hydrophones in Hawaii to cue bio-acoustic field research to minke whale locations has been demonstrated. The direct search effort in 2009 resulted in a rare visual sighting of a minke whale in Hawaiian waters.

SECR methodology holds promise for determining multiple species density using USN range hydrophones. As a result of this year's line transect survey conducted by T. Norris, an improved long term boing rate for minke whales enables converting cue densities into vocalizing minke whale density.

Future work is proposed to establish a multiple year baseline at PMRF for boing vocalizing minke whale density estimate (which would be the first multi-year marine mammal density estimate at a US Navy instrumented range). Future work would also be directed at arriving at robust density estimates requiring less manual effort and therefore cost

## **TRANSITIONS**

The improvements to the boing vocalizing minke whale density estimation methodology, initially developed in the DECAF project, can be adapted to the M3R system for use at US Navy instrumented ranges, and potentially extended to other species of marine mammals.

## **RELATED PROJECTS**

This effort is collaboration with the following principal investigators of projects with the same title: Tom Norris, Biowaves; and Vincent Janik and Len Thomas, University of St Andrews. Biowaves leads the field effort and conducted the acoustic line transect survey. The University of St Andrews supports the effort in the areas of survey design, density estimation methodology and towed

hydrophone analysis. An additional effort titled Passive Acoustic Tracking of Minke Whales by Eva-Marie Nosal also collaborates in this minke whale study in the area of minke whale passive acoustic localization processes.

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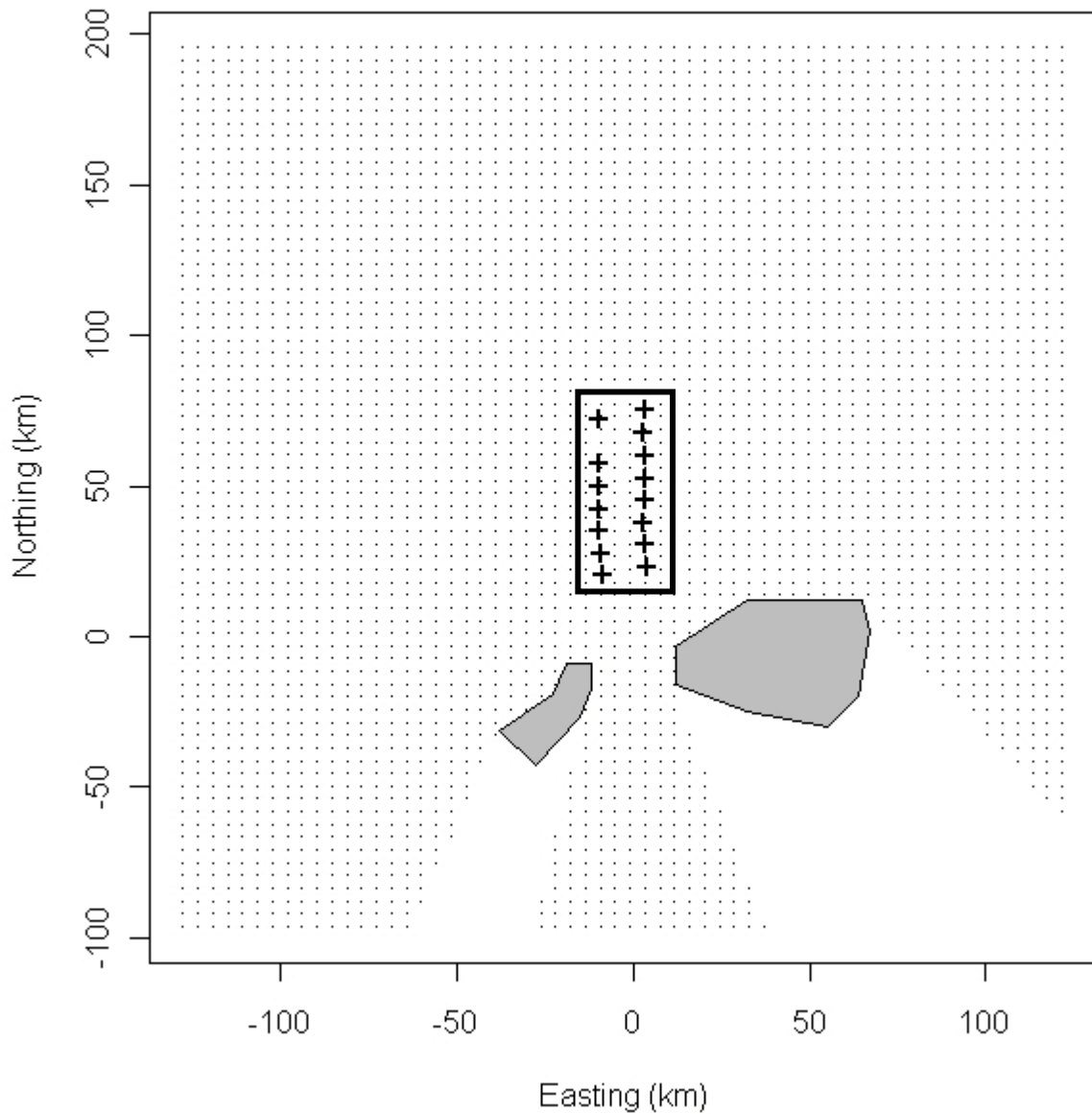
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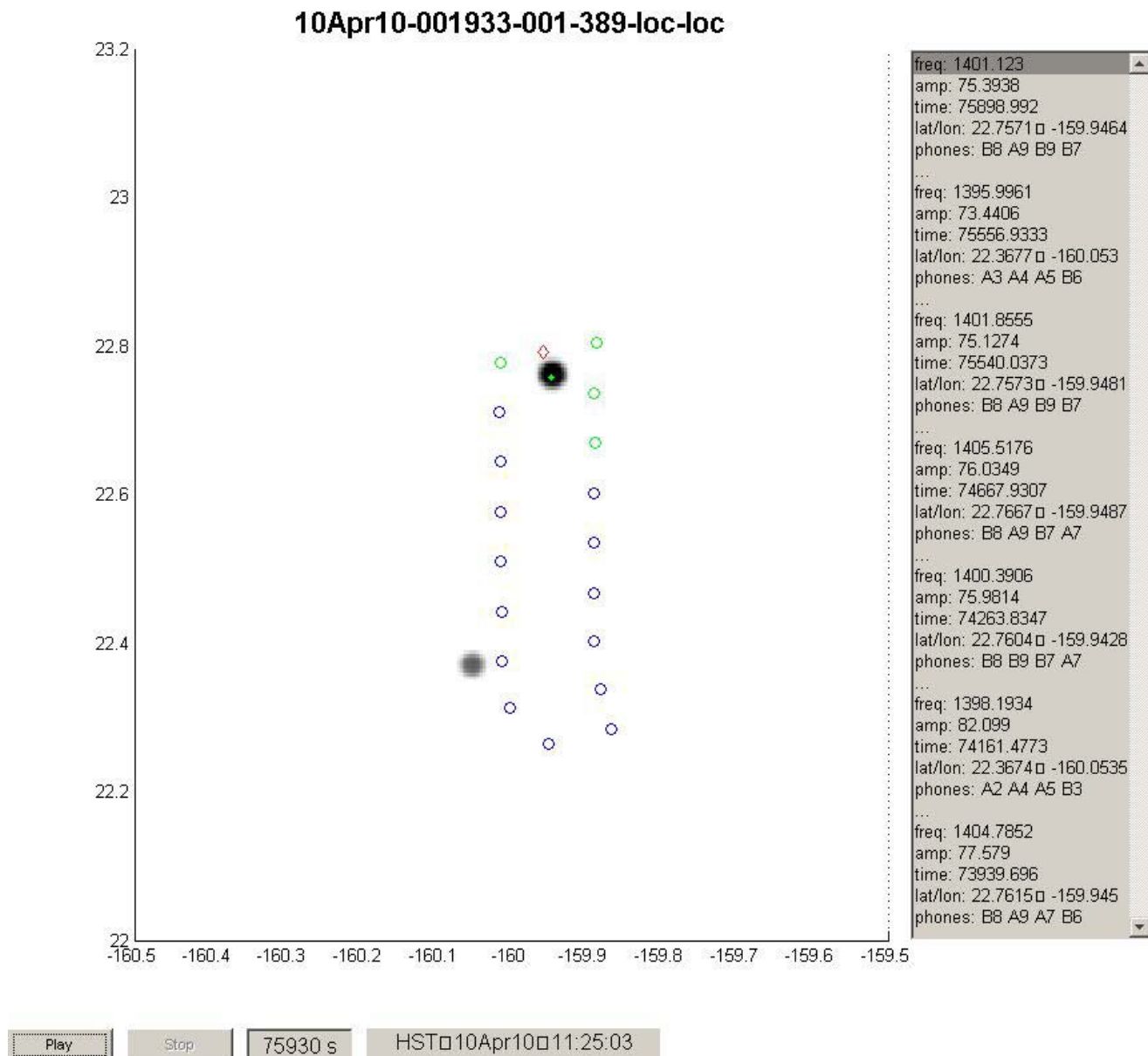
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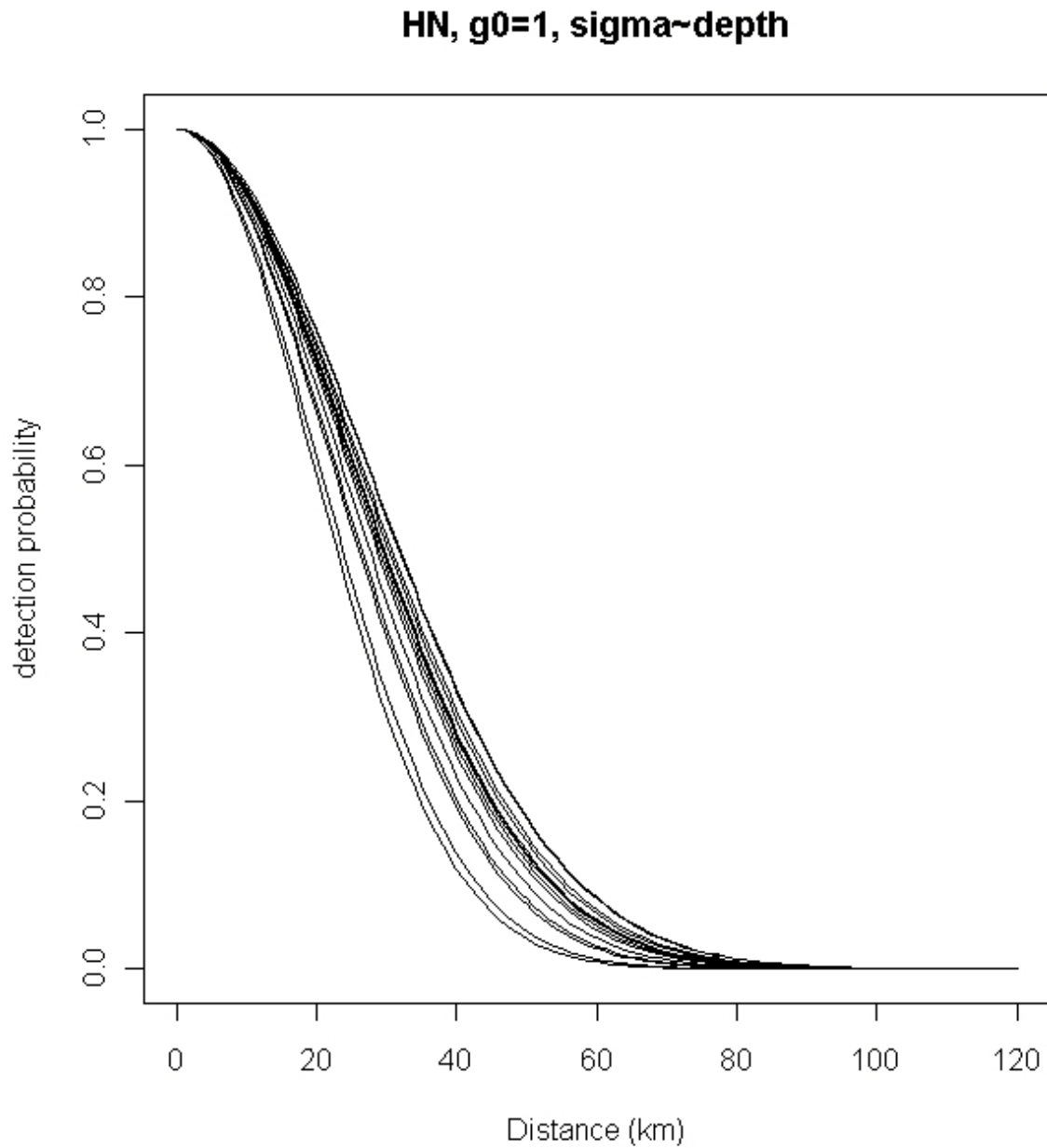


***Figure 1 – Study area located off the north north-west coast of Kauai, Hawaii showing the 15 hydrophones approximate locations (crosses), the habitat masked areas of the island masses (gray) and acoustic shadow zones due to the islands (no dots), and the approximate surface acoustic line transect survey area (boxed). The dots show areas utilized in the secr boing density analysis.***





**Figure 2 - Sample screen shot of matlab ‘movie’ of automatic localizations of minke whales, represented as dark circles, during the R/V Dariabar (red diamond) acoustic line transect at PMRF 10 April 2010 at 11:25 HST. Range hydrophone approximate locations shown as circles, green phones highlight those utilized for the current localization of the whale just below the R/V Dariabar. A second whale is observed to be on the southern end of the range at this time. Right panel shows text data of pertinent information on the late 7 automatic localizations.**



***Figure 3 – The fifteen (one for each hydrophone depth) half normal detection functions plotted against distance (km). The hydrophones with the shallowest depths have the shorter detection distances, while the deeper hydrophones detect boings to greater distance for the same probability of detection.***